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硕 士 学 位 论 文

南海北部与东海微型浮游动物类群组成及  
其对浮游植物摄食生态研究

Seasonal Variations of Microzooplankton Group  
Composition and Grazing on Phytoplankton in northern  
South China Sea and East China Sea

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## 摘要

分别于 2009 年 7-9 月、2009 年 12 月-2010 年 1 月和 2010 年 10 月-2010 年 12 月,应用显微分析技术和稀释法研究了我国南海北部和东海海区微型浮游动物类群组成、时空分布特征,表层和叶绿素最大层浮游植物的生长率及摄食死亡率,并初步探讨不同粒级浮游植物的生长率及摄食死亡率,获得如下主要结果:

南海北部海区表层微型浮游动物平均丰度为 1066 (sd.=1013) ind/L, 微型浮游动物平均生物量为  $2.16(\pm 2.12)$   $\mu\text{g C/L}$ 。无壳纤毛虫是微型浮游动物的优势类群, 占总丰度的 62%, 其中急游虫 (*Strombidium*) 和狭盗虫 (*Strobilidium*) 为优势属。叶绿素 *a* 最大层微型浮游动物丰度、生物量均与表层没有显著差异。表层不同区域 (近岸区、陆架区和海盆区) 微型浮游动物丰度与生物量并没有显著差异。表层夏季微型浮游动物的丰度和生物量显著高于秋季、冬季。三个季节微型浮游动物与环境因子的相关关系表明: 温度是南海北部微型浮游动物分布的一个显著影响因素, 温度越高, 微型浮游动物的丰度越高。而营养盐等其它因子与微型浮游动物分布并没有显著相关关系。但环沟藻属随着温度的升高, 其丰度和生物量均升高; 环沟藻属丰度与叶绿素 *a* 没有显著相关关系, 可能在南海, 细菌或者腐蚀碎屑是环沟藻食物的重要组成部分。

东海海区表层微型浮游动物平均丰度为  $1652(\pm 975)$  ind/L, 无壳纤毛虫是微型浮游动物的优势类群, 占总丰度的 73%, 其中急游虫 (*Strombidium*) 和狭盗虫 (*Strobilidium*) 为优势属。微型浮游动物生物量为  $3.57(\pm 2.89)$   $\mu\text{g C/L}$ 。叶绿素 *a* 最大层微型浮游动物丰度、生

物量均与表层没有显著差异。表层不同区域（近岸区、中陆架区和外陆架区）微型浮游动物丰度与生物量没有显著差异，不同季节（夏季、秋季、冬季）微型浮游动物的丰度和生物量也无显著差异。我们的结果表明东海微型浮游动物总丰度与生物量并不与温度或者叶绿素  $a$  值存在显著相关关系，但环沟藻属随着温度的升高，其丰度和生物量均升高；随盐度的升高，其丰度和生物量却降低；随着叶绿素  $a$  的升高而升高。

南海北部表层浮游植物生长率平均为  $0.75(\pm 0.39)$  /d，摄食率为  $0.44(\pm 0.34)$  /d。南海北部浮游植物生长率、摄食率并没有出现显著的季节变化，浮游植物生长率分别为夏季  $0.73(\pm 0.43)$  /d，冬季  $0.57(\pm 0.34)$  /d，秋季  $0.95(\pm 0.35)$  /d，摄食率分别为夏季  $0.51(\pm 0.48)$  /d，冬季  $0.36(\pm 0.21)$  /d，秋季  $0.43(\pm 0.27)$  /d。微型浮游动物对浮游植物的摄食压力分别为夏季  $65(\pm 48)\%$ ，冬季  $55(\pm 27)\%$ ，秋季  $45(\pm 24)\%$ 。不同水层生长率与摄食率进行比较可以看出：夏季表层浮游植物生长率与微型浮游动物摄食率均显著高于叶绿素  $a$  最大层 ( $p < 0.01$ )。而冬季南海北部表层浮游植物生长率显著高于叶绿素  $a$  最大层浮游植物生长率 ( $p < 0.05$ )，但冬季表层和叶绿素  $a$  最大层微型浮游动物摄食率并没有显著差异。三个季节温度与南海北部浮游植物生长率和微型浮游动物摄食率之间存在显著正相关关系，而叶绿素  $a$  与生长率之间没有检验出显著相关关系。夏季与冬季浮游植物生长率与叶绿素  $a$  值均成显著正相关关系。

东海表层浮游植物生长率平均为  $0.65(\pm 0.47)$  /d，摄食率为  $0.41(\pm 0.31)$  /d。东海表层夏季、秋季浮游植物生长率与摄食率均显著高于冬季。浮游植物生长率分别为夏季  $1.00(\pm 0.46)$  /d，秋季  $0.77(\pm 0.71)$  /d，冬季  $0.46(\pm 0.19)$  /d，微型浮游动物摄食率分别为夏季  $0.91(\pm 0.39)$

/d, 秋季  $0.47 (\pm 0.28)$  /d, 冬季  $0.22 (\pm 0.11)$  /d。微型浮游动物对浮游植物的摄食压力分别为夏季  $87 (\pm 38) \%$ , 冬季  $55 (\pm 30) \%$ , 秋季  $50 (\pm 17) \%$ 。不同水层浮游植物生长率与摄食率相比: 夏季和冬季表层浮游植物生长率与微型浮游动物摄食率均显著高于叶绿素  $a$  最大层浮游植物生长率和摄食率 ( $p < 0.05$ )。秋季微型浮游动物对  $< 5 \mu\text{m}$  的浮游植物摄食压力为  $54 (\pm 21) \%$ , 对  $> 5 \mu\text{m}$  的浮游植物的摄食压力  $53 (\pm 30) \%$ , 对不同粒级浮游植物的摄食并没有显著差异。三个季节温度与东海浮游植物生长率和微型浮游动物摄食率之间存在显著正相关关系, 而叶绿素  $a$  与生长率之间没有检验出显著相关关系。秋季微型浮游动物摄食率与叶绿素  $a$  值成正相关关系。

**关键词:** 微型浮游动物; 浮游植物; 季节变动; 摄食生态; 南海北部; 东海

## Abstract

Using the microscopic and dilution technique, we studied abundance, biomass, community composition of microzooplankton and their grazing impact on phytoplankton in northern South China Sea and East China Sea in three cruises (July-September 2009, December 2009-January 2010, October-December 2010). The main results were:

The mean ( $\pm$  SD) abundance of microzooplankton in northern South China Sea was 1066( $\pm$ 1013) ind/L. Microzooplankton was dominated by aloricate ciliates especially *Strombidium* and *Strobilidium*, which accounted for 62% of total abundance. The mean biomass of microzooplankton was 2.16( $\pm$ 2.12)  $\mu$ g C/L. The abundance and biomass of microzooplankton were not significantly different between deep chlorophyll maximum (DCM) layer and surface. The abundance and biomass of microzooplankton also were not significantly different among different areas or seasons in surface layer, although the mean values being higher in summer than in winter or autumn. Microzooplankton abundance was positively correlated with temperature; while other environmental factors were not correlated with microzooplankton abundance. There was also a positive correlation between *Gyrodinium* abundance and temperature, but not with other environmental variables.

Microzooplankton abundance in East China Sea averaged 1652( $\pm$ 975) ind/L. The dominating aloricate ciliates especially *Strombidium* and *Strobilidium* accounted for 73% of total abundance, The mean biomass of microzooplankton was 3.57 ( $\pm$ 2.89)  $\mu$ g C/L. The abundance and biomass of microzooplankton were not significantly different between deep chlorophyll maximum (DCM) layer and at surface. No significant difference of abundance and biomass of microzooplankton was found

among seasons or regions. We did not find significant correlation between total microzooplankton abundance and temperature or Chl *a* concentration. In contrast, there was a positive correlation between *Gyrodinium* abundance and temperature and also Chl *a* concentration.

Phytoplankton growth rate in the surface of northern South China Sea averaged  $0.75(\pm 0.39)$  /d, and microzooplankton grazing rate averaged  $0.44 (\pm 0.34)$  /d. There were no significant seasonal differences in phytoplankton growth rates and grazing rates. The average phytoplankton growth rates in different seasons were: summer:  $0.73 (\pm 0.43)$  /d, winter:  $0.57 (\pm 0.34)$  /d, autumn:  $0.95 (\pm 0.35)$  /d; the average grazing rates in different seasons were: summer:  $0.51 (\pm 0.48)$  /d, winter  $0.36 (\pm 0.21)$  /d, autumn  $0.43(\pm 0.27)$  /d. The variation of grazing effect of microzooplankton (the grazing: growth ratio) on phytoplankton in northern South China Sea was summer:  $65 (\pm 48)\%$ , winter:  $55 (\pm 27)\%$ , autumn:  $45(\pm 24)\%$ . In summer phytoplankton growth rates and grazing rates were significantly higher at surface than at deep chlorophyll maximum (DCM) layer. Phytoplankton growth rates were also significantly higher at surface and DCM layer in winter. There was positive correlation between phytoplankton growth rates or grazing rates with temperature but not with Chl *a* concentration when pooling the data of three seasons together. Positive correlation between phytoplankton growth rate and Chl *a* concentration was found in summer and winter.

Phytoplankton growth rate and microzooplankton grazing rate in the surface of East China Sea averaged  $0.65 (\pm 0.47)$  /d and  $0.41 (\pm 0.34)$  /d, respectively. Phytoplankton growth rates and grazing rates in the surface layer were significantly higher in summer than in winter and autumn. The average phytoplankton growth rates in different seasons were: summer:  $1.00 (\pm 0.46)$  /d, winter:  $0.46 (\pm 0.19)$  /d, autumn:  $0.77 (\pm 0.71)$  /d, the average grazing rates in different seasons were: summer:  $0.91(\pm 0.39)$  /d,

winter:  $0.36 (\pm 0.21)$  /d, autumn:  $0.47 (\pm 0.28)$  /d. The variation of grazing effect of microzooplankton on phytoplankton in East China Sea was summer:  $87 (\pm 0.38)\%$ , winter:  $55 (\pm 30)\%$ , autumn:  $50 (\pm 17)\%$ . In summer and winter, phytoplankton growth rates and grazing rates were significantly higher at surface than at deep chlorophyll maximum (DCM) layer. Grazing effect of microzooplankton on  $<5 \mu\text{m}$  phytoplankton was  $54 (\pm 21)\%$ , which was not significantly different from  $>5 \mu\text{m}$  phytoplankton ( $53 \pm 30\%$ ) in autumn. There was positive correlation between phytoplankton growth rates or grazing rates with temperature but not with Chl *a* concentration when pooling the data of three seasons together. Positive correlation between phytoplankton growth rate and Chl *a* concentration was found in autumn.

**Key words:** Microzooplankton; Phytoplankton; South China Sea; East China Sea; Season variation

## 第1章 绪论

### 1.1 微型浮游动物的生态作用

微型浮游动物是指体长 2-200  $\mu\text{m}$  的浮游动物。微型浮游生物按照粒级可分为微微型浮游生物 (picoplankton, 0.2-2.0  $\mu\text{m}$ )，微型浮游生物 (nanoplankton, 2-20  $\mu\text{m}$ ) 和小型浮游生物 (microzooplankton, 20-200  $\mu\text{m}$ ) (Sieburth et al., 1978)。微型浮游动物包括原生动物和后生动物，具体分类类群见表 1。为研究方便，通常将小型浮游动物以及微型浮游动物合并称为微型浮游动物 (Murrell & Holli-baugh, 1998)，主要类群有纤毛虫、异养鞭毛虫、异养甲藻、桡足类幼体等，本文即以此为研究对象。

表 1 微型浮游动物的类群组成 (Porter & Sherr, 1985)

Table 1 Composition of microzooplankton groups

粒级	Pico-级	Nano-级	Micro-级
微型浮游动物	异养鞭毛虫	异养鞭毛虫 无壳纤毛虫	无壳纤毛虫，砂壳纤毛虫， 异养甲藻，桡足类幼虫， 轮虫，有孔虫等

近几十年来，有关海洋生物的地球化学过程方面的研究在概念和技术上都有了新的发展和突破。特别是微食物环 (Microbial loop, Azam et al., 1983)，生物泵 (Biological pump, Longhurst & Harrison, 1989)，微微型生物食物网 (Picoplankton food web, Barber, 2007) 等概念的提出，进一步显示了生物过程在海洋碳循环中的研究意义与重要性。一般认为，微食物环是指浮游生物分泌的可溶性有机质被异养细菌利用，转变成细菌颗粒物；异养细菌又被微型浮游动物所摄食，再通过桡足类等中型浮游动物进入经典食物网中；或者微微型浮游植物被微型浮游动物摄食，再通过桡足类等中型浮游动物进入经典食物网中 (图 1.1)。微型浮游动物作为异养细菌和微型浮游植物的摄食者，在微食物环



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